# 2152

# Tomentosus Root Rot:
## Comparisons of Disease Expression and Management Between Alaska and British Columbia, Canada

Technical Report R10-TP-83


ABSTRACT

Tomentosus root rot, is a widespread and important root rotting fungus of spruce (*Picea* spp.) and pine (*Pinus* spp.) in Alaska and British Columbia, Canada. Disease incidence and expression is similar within the two regions. There is potential for an increase in disease incidence in managed stands over time as a result of forest management practices. Occurrence of the root rot within managed recreation areas may create hazardous conditions. Comparisons of disease expression and management in Alaska and British Columbia are presented. Recommendations for disease management, survey work, and research studies in Alaska are included.



USDA United States Department of Agriculture | Alaska Region | Forest Service

UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA

# Tomentosus Root Rot:
## Comparisons of Disease Expression and Management Between Alaska and British Columbia, Canada

TECHNICAL REPORT R10-TP-83

October 2000

Prepared by:

Kathy J. Lewis, Associate Professor
Forestry Program
University of Northern British Columbia
Prince George, British Columbia

Lori M. Trummer, Pathologist
Forest Health Protection
Region 10, Alaska

Approved by:

Jerry Boughton, Program Manager
Forest Health Protection
Region 10, Alaska

For

Paul W. Forward
Deputy Regional Forester
Region 10, Alaska

University of Northern British Columbia
Forestry Program
3333 University Way
Prince George, British Columbia
Canada V2N 4Z9

USDA Forest Service
Alaska Region
State and Private Forestry
3301 C Street, Suite 522
Anchorage, AK 99503

# Table of Contents

# I. INTRODUCTION

Tomentosus root rot, caused by the fungus *Inonotus tomentosus*, is a widespread root rotting fungus of conifers in the boreal and sub-boreal forests worldwide (Whitney 1977). In Alaska, the presence of the disease has been confirmed across the south-central and interior regions. This disease causes growth loss, butt cull, and mortality of many spruce and pine tree species. The root rot fungus can attack susceptible trees of all ages, including seedlings, through root contacts.

Research on tomentosus root rot has been conducted primarily in western Canada, resulting in disease guidelines for intensively managed spruce forests. In Alaska, many gaps remain in our understanding of the biology and ecology of tomentosus root rot, yet this information is critical for proper management of the disease. Application of the research and management guidelines developed in Canada for use in Alaska deserves careful consideration.

The purpose of this report is to provide comparisons of tomentosus root disease expression and management between Alaska and Canada. The validity of applying the research and management guidelines developed in Canada to Alaskan forests with tomentosus root rot is presented.

# II. DISEASE EXPRESSION

## A. Distribution and Hosts

Tomentosus root rot has worldwide distribution in the boreal and sub-boreal forests of North America, Europe, and Asia (Whitney 1977). In Canada, most native pine species and all native spruce species are attacked by the root rot, but the disease is predominantly found on spruce (Whitney 1977).

In Alaska, the first documented report of tomentosus root rot on white spruce (*Picea glauca*) was by visiting mycologists (Kimmey and Stevenson 1957). They considered the pathogen to be rare within the region. However, recent forest surveys detected the disease within spruce forests across south-central and interior Alaska, indicating that the pathogen is much more widespread than originally thought. The limited area surveyed by visiting scientists and the inconsistent fall fruiting of fungus likely contributed to the rare identification of the fungus in early surveys. To date, tomentosus root rot has not been detected in the coastal forests of southeast Alaska.

In Alaska, all native spruce species, white, black (*P. mariana*), Sitka (*P. sitchensis*), and Lutz spruce (Sitka and white spruce hybrid *Picea* x *lutzii* ) are considered highly susceptible to infection by the root rot (Whitney and Bohaychuk 1976). The native tamarack (*Larix laricina*) and a broad range of pine species (*Pinus* sp.), including lodgepole pine (*P. contorta*), are susceptible to infection (Whitney and Bohaychuk 1976). Although pines are not native to south-central and interior Alaska, some species are planted in various forest and

urban settings. To date, there are no reports of natural infection of hardwood trees, although successful artificial inoculations have been made on birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*) (Whitney 1964). Hardwood trees are considered immune to natural infection by tomentosus root rot.

## B. Pathology of Tomentosus Root Rot

### Symptoms and Diagnosis

Colonized roots of infected spruce trees have decayed wood with spindle-shaped pits and a red/brown to pink stain. The decay and stain caused by tomentosus root rot in Alaska is very similar to the signs of the disease in central British Columbia. In the early stages of decay, a dark pink to pinkish-brown stain is evident in the roots, normally in the heartwood. At this early stage, the pits are very small and often slightly yellowish. As decay progresses, these expand into a honeycombed pattern of white pits. In extremely advanced decay, the pits no longer contain mycelium, but the honeycomb pattern remains.

Above-ground fruiting bodies, or conks, normally appear from mid August to October, but their production is weather-dependent. Therefore, trees without conks may still be infected. Conks develop on the ground, arising from infected roots around diseased trees. Conks are leathery, small, round to oval, stalked and have pores (not gills) on the underside that continue part way down the stalk. The lower surface is cream to yellow-brown while the upper surface is tan to yellow-brown with a velvety or hairy texture. Absolute identification of the disease occurs only through examination of conks or culturing the fungus from decayed wood. However, uprooted trees with honeycombed pattern in the decayed roots, and the pattern of small groups of infected trees can strongly suggest that *I. tomentosus* is the agent causing the root rot.

FIGURE 1. Severe crown symptoms

Tomentosus root rot causes a slow dysfunction of the root system. Above-ground symptoms exhibited by infected trees are similar to those caused by other root diseases. These include thin crowns, reduced leader growth, and chlorosis (Figure 1). Foliar symptoms are generally not obvious until the fungus is well-advanced in the root system, and are therefore not reliable for diagnostic purposes. Diseased trees may not have any obvious above-ground symptoms, making diagnosis particularly difficult. On relatively moist sites, there may be little difference in appearance between uninfected and infected trees during the early stages of colonization.

Infected trees eventually die standing, snap at the lower bole, or more commonly, uproot (Figure 2). Uprooted trees typically have short sections of major roots attached with obvious pits within the decayed root wood. When viewed end-on the pitted roots have a honeycombed appearance. Cross-sections of infected stump tops also may exhibit a honeycombed pattern.

FIGURE 2. Uprooted spruce with extensive root rot

Spatially, tomentosus root rot typically occurs in small clumps, often only 2-3 trees per clump, with the clumps gradually coalescing into larger areas of dead and infected trees in various stages of decline. Tomentosus root rot in Alaska appears to cause a similar pattern of mortality to that seen in British Columbia.

## Other Similar Fungi

Two other fungi that occur in boreal forests, *Phellinus pini* and *Inonotus circinatus*, may confuse diagnosis of tomentosus root rot. *Phellinus pini* is a true heart rot fungus of conifer trees. It enters trees through natural openings such as twig or branch stubs and colonizes the central part of the tree. The pattern of decay is very similar to tomentosus root disease in that they both cause honeycombed pitting in the wood. Tomentosus root rot enters trees through the root system whereas *P. pini* causes a heart rot and enters the tree above-ground. However, tomentosus root rot can move up the bole from the roots, and *P. pini* can move into the roots from the bole, so location of the decay is not a reliable feature to distinguish the two fungi. In the field, one should look for tomentosus occurring in clumps of several trees, which indicates a fungus that spreads by root contacts, as compared to single, isolated occurrences of the decay, suggestive of a heart rot fungus, such as *P. pini*.

*Inonotus circinatus* is a closely related root and butt rot fungus. The conks of *I. circinatus*, however, are larger, thicker, and shelf-like on dead roots or at the base of infected stems. Examination of fruiting bodies is necessary to distinguish *I. circinatus* from tomentosus root rot. To date *I. circinatus* has not been detected in Alaska but is found in the boreal forests of British Columbia. This fungus causes similar symptoms in spruce but its extent and virulence are unknown in Western North America.

## Disease Cycle

Little is known about the infection process of tomentosus root disease. The fungus can spread from infected roots to roots of uninfected trees across root contacts, and it is thought

that the fungus is able to directly penetrate the bark of small roots (less than 5 cm diameter). Mycelium of the fungus has been observed on the exterior surface of roots of various sizes. This mycelium may play a role in spread of the fungus.

Once infection does occur, the fungus spreads within the roots and towards the base of the tree, eventually reaching the heartwood in the butt. The fungus usually grows longitudinally in the heartwood; radial spread into the sapwood is limited until the tree is extremely stressed or dead. At this point the fungus spreads radially more than longitudinally. Once sufficient food base is colonized, the fungus may produce above ground fruiting bodies that are connected to colonized roots.

There is evidence indicating that the pathogen is spread by spores. Neighboring clumps of infected trees may originate either from separate spore infections, or clonally by root contacts. Although the role of spore dispersal in the spread of the fungus is unknown, spores do clearly initiate new, genetically distinct, infection centers.

The size of tomentosus root rot clones has been used in B.C. to study variation in fungal spread rate as a function of moisture regime and species composition. Three site types were studied that varied in soil moisture from wet to generally well-drained. There were no significant differences in clone sizes between the three different site types, or in number of trees/clone by site series. However, statistically, average clone size per plot and number of clones per plot did show a significant relationship with the percent of spruce per plot (K. Lewis, unpublished data).

Results from the B.C. clone study indicate that greater spruce density leads to: 1) greater spread of the fungus from tree to tree resulting in larger clone sizes; and 2) increased incidence of spore infections resulting in new infection centers. Additional laboratory work on cultures of the fungus indicated that many of the clones within the study plot are genetically related, resulting from spore infection from the same, or a closely related, fruiting body.

Effects on Host

Trees infected with tomentosus root rot may be killed outright, predisposed to uprooting, or predisposed to collapse of the lower bole. Infected trees also grow slower than healthy trees and often contain significant amounts of decayed wood. The magnitude of loss varies with the level of infection within any one stand. The net volume of trees is not significantly affected until more than 75% of root system is infected. The decrease in volume is due in part to reduction in growth increment, but mostly to an increase in butt cull volume. Up to 32% of potential volume may be lost through butt cull (Lewis 1997). Wood decay from tomentosus root rot may extend 8 to 10 feet up the stem.

Trees infected with tomentosus root disease show a gradual growth decline relative to healthy trees. The rate of decline increases with disease severity and time. At the early stages of infection, the fungus is found primarily in the heartwood of larger roots with a few smaller roots being killed (Lewis et al. 1992). As the disease progresses and more roots are

killed, the tree loses vigor and the fungus will move into the sapwood of larger roots as a result of decreased defense capability. This results in accelerated growth reductions in the latter stages of disease progression. The most significant growth reductions are observed in the most recent growth periods, indicative of a progressive root disease.

Disease progression appears to be faster in small trees because there is less root volume to compensate for roots rendered dysfunctional by the fungus. However, small trees are less likely to become infected than large trees because they are less likely to come into contact with inoculum, again due to the smaller root systems (Lewis 1997).

It is thought that *I. tomentosus* is able to infect vigorous trees as easily as stressed trees. However, once the fungus is in the tree, mortality may occur earlier in trees that are stressed by other factors. Tomentosus root disease itself is thought to predispose trees to attack by some bark beetles, root collar weevils and other agents that typically inhabit stressed trees (Lewis and Lingren 2000).

## C. Ecology and Relationship to Other Disturbance Agents

<u>Ecological Role of Tomentosus Root Disease</u>

In many forest ecosystems, root diseases have an ecological role in creating canopy gaps that contribute to biodiversity, wildlife habitat and other ecosystem features. In British Columbia, canopy gaps due to tomentosus root disease are usually very small in functional size (Newberry[1] et al., unpublished data). The ecological function of small gaps caused by tomentosus root rot is not known, but may include altering wildlife habitat and successional processes.

In Alaska, tomentosus root rot causes small canopy openings and expanding mortality centers. Non-host species, including hardwoods, tend to re-establish within root rot centers, although this is dependent on available seed sources. Thus, tomentosus root rot may alter successional pathways in mixed stands and increase plant diversity by opening the canopy in a somewhat sporadic fashion across both space and time.

The incidence of infection by tomentosus root rot varies with some site and soil characteristics in the wet, cool sub-boreal spruce forests of central British Columbia. The most important variables influencing disease incidence are suggested to be: 1) moisture regime and slope position; 2) the rooting depth of spruce trees, which is related to the soil nutrient regime and humus form; and 3) the number of root contacts that occur between susceptible roots (Bernier and Lewis 1999). In Alaska, no studies have been undertaken to explore the soil and site relationships with the incidence of tomentosus root rot.

<u>Spruce Beetle</u> (*Dendroctonus rufipennis*)

Results from studies in the central interior of B.C. suggest that tomentosus root disease does not make a significant contribution to the development of epidemic spruce beetle populations

---

[1] Ted Newbery, MSc Thesis in progress, University of Northern British Columbia, Prince George.

(Lewis and Lingren 2000). At epidemic population levels, there are other factors that have more influence on beetle success than the presence of root disease. At endemic beetle levels, however, there may be a weak relationship between the two organisms. We expect similar relationships between spruce beetles and tomentosus root disease in Alaska.

Results from surveys to sample incidence of root disease and bark beetles and from measurements of phloem thickness taken during a phermone baiting experiment indicated a weak association between the two organisms (Lewis and Lingren 2000). Pairs of spruce trees were baited with spruce beetle pheromone in two stands, one with endemic beetle populations and the second with outbreak levels. Within each pair of baited trees, one tree was infected with tomentosus root rot and its pair was healthy. Results at the site with endemic population levels suggest that tomentosus root rot-infected trees provide a more suitable environment for brood establishment due to reduced defensive capabilities of the tree. As the disease progresses, the tree's defences become more limited and beetle success rate appears to improve. At some point in disease development, however, when the fungus has advanced into the sapwood and inner bark, shortly before tree death, the environment for the beetle appears to become less suitable. This was supported by observations in the surveying phase of the study.

At endemic beetle levels, the association between root disease and susceptibility to beetle attack is conceptually modelled in Figure 3. The figure indicates a window of opportunity in root diseased trees where host suitability for bark beetles is greater than in healthy trees.

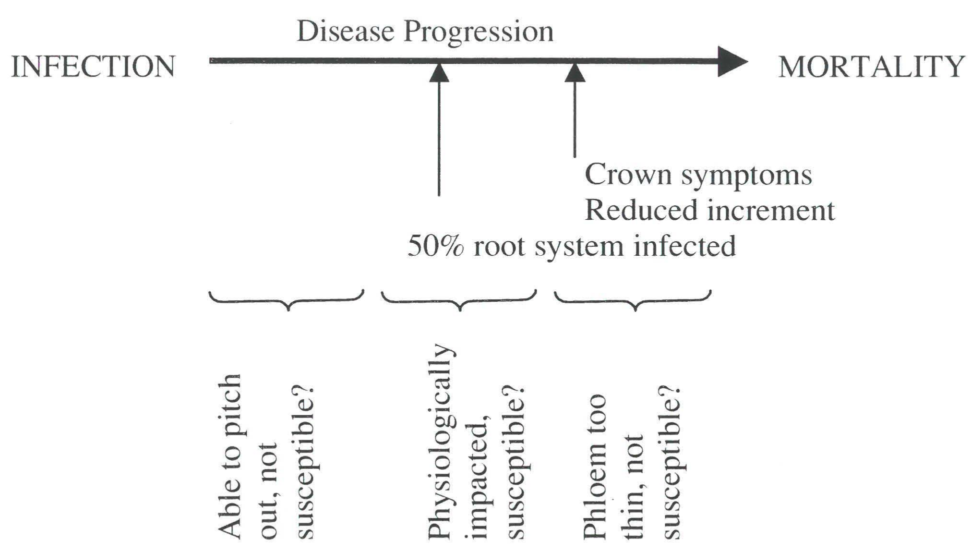


FIGURE 3. Conceptual model of the relationship between endemic levels of spruce beetle, and tomentosus root disease.

The relationship between spruce beetle attack and disease severity observed at the endemic site, was not observed at the outbreak site. Stands with high levels of spruce beetle sampled in the first phase of the study showed very little association between beetle attack and root disease. It is suggested that at high beetle populations, the pressure of attack on the host is

greater than the impact of the root disease on defence response and therefore overwhelms the root disease effect.

Other root disease /beetle associations reported in the literature (e.g. Tkacz and Schmitz 1986) have indicated a stronger association. However most other root disease fungi, such as *Armillaria ostoyae* and *Phellinus weirii*, kill trees faster than *I. tomentosus* does. Tomentosus root disease causes a slower decline or chronic stress that may affect beetle behaviour and success differently than the more acute stresses induced by more aggressively pathogenic root diseases. Furthermore, spruce trees are generally shallow rooted and in sub-boreal forests, are often found in moister areas with thin soils. As a result, windthrown spruce are common in most spruce stands and the availability of this resource to spruce beetles may outweigh the impact of the root rot on host trees.

Fire

There is no evidence that fire, natural or prescribed, has any direct effect on tomentosus root disease inoculum or disease spread in Alaska or British Columbia. Root disease has been observed at relatively high levels on sites planted with spruce following a prescribed slash burn. Root disease has also been observed on sub-boreal forest sites where dendrochronology and buried charcoal indicate the occurrence of a significant stand-replacing wildfire within the past several centuries (K. Lewis, personal observation). During a fire, surface temperatures up to 450°C would have little effect more than 5cm below the soil surface in most northern soils (Viereck and Schandelmeier 1980). Soil temperature measurements taken at several depths before and after a prescribed burn at Washington Creek in interior Alaska indicated little or no fire-related temperature change (Viereck and Schandelmeier 1980). Therefore, soil temperatures are not expected to be hot enough or deep enough to substantially reduce inoculum loads in stumps or buried roots. This is supported by research in the Pacific Northwest on laminated root rot which indicates that prescribed burn sites and unburned sites do not differ substantially in incidence of root disease (Thies 1990). Chemical changes within the soil due to ash leachates may influence populations of fungi antagonistic to root disease, however, the long term effects of these changes are poorly understood (Reeves et al. 1984, Filip and Yang-Erve 1997).

Indirect effects of fire, such as stand composition changes, may alter root disease incidence. Fire, particularly stand-replacing fire, causes shifts in forest succession. In Alaska, colonization of sites after stand-replacing fires is frequently dominated by hardwoods (Viereck and Schandelmeier 1980). These seral species are immune to tomentosus root disease. The reduction in host tissue available to the fungus following a fire may result in a reduction in inoculum load by the time spruce recolonize the site. In some sub-boreal forests of British Columbia however, recent research has indicated that in the absence of a seed source for hardwoods, spruce recolonizes sites burned by wildfire (DeLong 1998). In this situation, the inoculum load is expected to decrease until the new spruce trees' root systems were large enough to contact the inoculum and become infected.

# III. FOREST MANAGEMENT

## A. Disease Incidence and Implications for Management

In central B.C. the incidence of tomentosus root rot varies by stand. Few spruce-dominated stands have no disease, and many stands have an incidence of 5-8% trees infected. At some locations, up to 40% of trees are infected. Disease incidence in south-central and interior Alaska appears similar to that in B.C in that incidence of root rot varies by stand and many stands have a low (<5%) to moderate (6-15%) incidence of spruce trees infected. Recent surveys of managed stands on the Kenai Peninsula indicate that disease incidence in infected stands ranges from 1 to 17% of spruce trees (L.Trummer, unpublished data). The disease is present in interior Alaska, but few incidence surveys have been conducted in this region.

Spatial relationships among diseased trees are similar for Alaska and British Columbia. The disease appears in groups of a few infected trees and these groups are clumped within a given stand (Lewis and Hansen 1991). This clumped distribution is important in terms of disease management. It means that stands scheduled for harvest can be stratified by disease incidence, resulting in reduction in treatment cost and increased efficacy. Stands can be stratified by using ecological indicators of where disease is likely to be found (if available) and/or by ground surveys.

Replanting harvested sites with spruce will likely lead to an increase in disease incidence in future rotations due to the opportunity for tomentosus root rot to spread from stumps directly into young trees (Lewis and Hansen 1991). In B.C., the fungus remains alive in stumps and larger roots for at least 30 years. The likelihood of root contact with infected stumps or roots and the likelihood of infection is inversely proportional to distance from a colonized stump. Trees planted within 2m of a colonized stump have a 25% chance of infection, and trees planted within 3.75m have a 10% chance of infection. (Lewis and Hansen 1991). It is expected therefore, that spruce density will have a significant impact on root disease incidence due to the increased chance of root contacts with diseased roots.

## B. Assessments and Management Options

<u>Quantification Methods</u>

In British Columbia, the quantification of tomentosus root disease by forest managers falls into one of two categories: pre-harvest and post-harvest assessments.

Pre-harvest assessment involves sampling standing trees. Due to the lack of symptom expression in lightly to moderately infected trees, above-ground symptoms are not reliable indicators of disease incidence. Root sampling is necessary for an accurate estimate. Research in British Columbia determined that sampling 2 roots per tree provided sufficient accuracy for diagnosis. Depending on the survey objectives, the percent of area covered by the survey can range from 1% to 10%, and can be done by transects or plots. Root sampling is laborious and time consuming. It is possible to reduce the number of trees being sampled by only sampling those trees that are in the vicinity of some disease source as indicated by

clumps of standing dead trees or windthrown trees with root balls, and that aren't obviously infected. It is also possible to reduce survey costs by pre-stratifying stands based on ecological indicators. For example, areas that consistently have a high water table (e.g. bogs) will probably have very little or no root disease and can be eliminated from surveys.

Post-harvest surveys involve a survey of stump-tops for the pitted decay which can be seen at the stump surface of trees with butt rot. This procedure is much less costly and allows greater precision. According to Lewis and Hansen (1991) approximately 80% of infected spruce trees have butt rot as well, so a stump-top survey will miss approximately 20% of the infected trees. The drawback to this procedure is that it limits management options because it is performed post-harvest. Also stump assessments need to be conducted by trained personnel as the decay pattern of tomentosus root rot is easy to misidentify and is similar to other root and stem decay fungi.

<u>Three-stage Survey</u>

The British Columbia Forest Service has developed a three-stage survey procedure for all root diseases occurring within the province:

*Stage 1: Landscape hazard and risk assessment*
This identifies forest types and species compositions that are most likely to have root disease and therefore are most in need of surveys.

*Stage 2: Prescription walkthrough*
This stage is performed at the time of the Silviculture Prescription (SP) survey. This survey is to collect information necessary for the SP. However, a walkthrough of the stand can be performed at any time. The intent is to approximate root disease incidence and to stratify the stand by disease incidence. If the area has no root disease, or the incidence exceeds the maximum (15% of stems infected for tomentosus), no further surveys are required and a prescription is made depending on an assessment of future stand risk and stand management objectives. If the area has a root disease incidence between the minimum and maximum (6-15%), a further survey is required.

*Stage 3: Root disease assessment survey*
This can be carried out using a variety of methods such as those described below. The results of this survey are used to stratify the area by disease incidence, and to determine future stand risk. This information is then combined with site constraints, management objectives, treatment options etc. to develop a prescription.

<u>Developing a Management Strategy</u>

Management of this disease should begin in the planning and pre-harvest stages of forest management. Once a stand is regenerated, the options for management are more limited.

In general, management strategies are in three categories: 1) establishing an alternative species that is less likely to become infected either because the species is less susceptible

(e.g. hardwood tree) or its rooting habit results in slower spread; 2) establishing a mix of host and non-host species that decreases the potential for root contacts due to differences in rooting habit; and 3) removal of diseased material from the soil.

The British Columbia Forest Service has developed guidelines to assist forest managers with root disease management. These include the "3m rule" which states that susceptible trees should not be planted within 3m of a tree or stump infected with tomentosus root disease. This is intended to reduce the likelihood for root contact between colonized stumps and regeneration trees. In areas where the incidence of root disease was relatively high prior to harvest, and where tree species choices are limited, implementation of this guideline can lead to insufficiently stocked plantations. However, in areas where root disease incidence is low, this "avoidance planting" approach may be quite successful if natural in-growth of susceptible conifers is limited.

Effects of Stand Thinning on Root Disease Incidence

Stand thinning on infected sites may increase the incidence of tomentosus root disease. This is presently under investigation in the central interior of B.C. Currently in B.C., it is recommended that thinning of trees in young stands, or partial cutting of mature stands be avoided in areas where *I. tomentosus* is present. This is because it is possible that thinning or partial cutting will increase the amount of inoculum in cut stumps (due to increased radial spread of the fungus in the roots) and therefore increase the rate of spread to surrounding residual trees. On-going research will provide a much broader picture of the effects of stand thinning on infected sites.

Hazard Trees

Recognition of root diseased trees is part of an aggressive and pro-active hazard tree management program. Tomentosus root rot has been documented in live trees in one south-central Alaska campground (Schulz-Blitz 1991) and occurs in other managed recreation sites in the region (L. Trummer, personal observations). Smaller infected trees are likely to die standing, while large diameter trees with damaged or dead roots due to a root disease are likely to uproot, resulting in whole tree failure. If tree failure occurs within striking distance of a valuable target, a hazard to life and property exists. Regeneration of spruce trees within root rot centers will serve to maintain and likely increase the disease on an infected site. Development of a comprehensive vegetation management plan will assist managers in evaluating present and future vegetation changes from root diseases and other disturbance agents.

## C. Management Options for Tomentosus Root Rot in Alaska

A reasonable approach to management of root disease in Alaska is through pre- and post-harvest surveys and cultural techniques. The three-stage surveys developed in B.C. can be adapted for use in Alaska. The success of this approach will depend on accurate and thorough root rot surveys to determine disease severity levels and distribution. Results from

these surveys can then be used to determine a reasonable management strategy tied to the level of root disease on a site and landowner objectives.

Stands can be stratified by disease incidence resulting in reduced treatment costs and increased efficacy. To consider using this "soft" approach to root disease management requires information on disease incidence and variation at the stand and watershed or landscape level (see IV. Recommendations).

Where root disease incidence is high enough to warrant action (>5% incidence), management options available to landowners in Alaska include:

1. Establishing alternative species on infected sites.

   One of the difficulties forest managers in Alaska will face is the lack of conifer species diversity in Alaska's south-central and interior ecosystems. The current preferred method of root disease management in central B.C. is use of alternative conifer species. In Alaska, all native conifer species are considered highly susceptible to infection by tomentosus root rot, but all hardwood species are considered immune to the disease. Thus, a reasonable option is to establish or encourage hardwood regeneration, i.e. paper birch or trembling aspen, on infected sites until the root rot is no longer viable. A hardwood rotation of 20 to 40 years is expected to substantially reduce the viability of tomentosus root rot.

2. Avoidance plant with the 10ft (3m) guideline.

   The 3m planting guideline from B.C. can be successfully utilized as a management option in Alaska. To substantially reduce the likelihood of tomentosus root rot spread, replanting or re-establishing spruce should occur at least 10ft (3m) from a tree or stump infected with tomentosus root disease. In areas where root disease incidence is low, this approach may be quite successful if natural regeneration of spruce is limited. Accurate and thorough root rot surveys are needed to determine disease distribution within stands.

3. Removal of infected root material.

   There are several operational trials into de-stumping infected sites in B.C., although none of these have yet yielded sufficient data on efficacy of root disease control, soil compaction and other variables. This strategy is quite expensive, is site-dependent, and is not currently practical in B.C. In Alaska, site productivity on many of the sites visited seemed quite low (K.Lewis, personal observations). This suggests that inoculum reduction by stumping, will cost more than the benefit gained from the reduction in root disease.

# IV. RECOMMENDATIONS

## A. Survey Needs in Alaska

It is recommended that information be collected on the incidence of root disease at the stand and landscape/watershed level in Alaska. Improved estimates of disease incidence and severity are necessary to ensure the development of management options and opportunities.

Surveys of standing timber can be conducted in connection with other survey work carried out for silviculture or other purposes. An efficient tomentosus root rot survey method is post-harvest stump top surveys. These surveys, conducted in stands that will be replanted with spruce, would provide valuable cost-effective information for site specific management decisions.

## B. Research Needs in Alaska

An important area of research that would be directly applicable to root disease management in Alaska is the identification of ecological indicators (e.g. soil moisture) of areas where a high incidence of root disease is expected. These indicators are helpful tools in disease identification by identifying areas where particular attention should be paid to disease surveying. The indicators are also useful in landscape level estimation of root disease incidence because ecological information is often more accessible and less expensive to collect than root disease survey information.

A second area of needed research is on the relationship between spruce density and disease incidence and severity. This question was raised in work by Bernier and Lewis (1999), and is particularly relevant in Alaska due to highly variable stand densities and the frequency of natural mixed-wood stands.

Mixed spruce/hardwood stands are common in south-central and interior Alaska. A third area of needed research explores the relationship between species composition and disease incidence. This information is necessary for both ecological and forest management considerations. The research could take several approaches:

- Quantify relationships between root disease incidence and species composition.

- Examine the underlying mechanisms for hardwood resistance to tomentosus root rot. These mechanisms may include differences in bark chemistry and anatomy or the presence of beneficial microbes in the rhizosphere of hardwood species.

- Examine the ecological influences of spruce mortality due to tomentosus root rot on species composition and stand structure.

## LITERATURE CITED


Bernier, D. and Lewis, K.J. 1999. Site and soil characteristics related to the incidence of *Inonotus tomentosus*. Forest Ecology and Management 120:131-142.

DeLong, C. 1998. Natural disturbance rate and patch size distribution of forests in northern British Columbia. Implications for forest management. Northwest Science (special issue) 72:35-48.

Etheridge, D.E. 1956. Decay in subalpine spruce on the Rocky Mountain Forest Reserve in Alberta. Canadian Journal of Botany 34:805-816.

Filip, G.M. and Yang-Erve, L. 1997. Effects of prescribed burning on the viability of *Armillaria ostoyae* in mixed-conifer forest soils in the Blue Mountains of Oregon. Northwest Science 71:137-144.

Kimmey, J.W. and Stevenson, J.A. 1957. A forest disease survey. Plant Disease Reporter, Supplement 247:87-98.

Kuhlman, E.G. 1980. Influence of moisture on rate of decay of loblolly pine root wood by *Heterobasidion annosum*. Canadian Journal of Botany 58:36-39.

Lewis, K.J. 1997. Growth reduction in spruce infected by *Inonotus tomentosus* in central British Columbia. Canadian Journal of Forest Research 27:1669-1674.

Lewis, K.J. and Hansen, E.M. 1991. Survival of *Inonotus tomentosus* in stumps and subsequent infection of young stands in north central British Columbia. Canadian Journal of Forest Research 21:1049-1057.

Lewis, K.J. and Lingren, B.S. 2000. The relationship between spruce beetle and tomentosus root disease: two natural disturbance agents of spruce. Prepared for the Joint CPS/APS Pacific Division conference, June 18-21, 2000, Victoria B.C.

Lewis, K.J., Morrison, D.J., and Hansen, E.M. 1992. Spread of *Inonotus tomentosus* from infection centers in spruce forests in British Columbia. Canadian Journal of Forest Research 22:68-72.

Medinger, D. and Pojar, J. 1991. Ecosystems of British Columbia. Ministry of Forests, Research Branch, Crown Publications, Victoria, B.C. 330pp.

Reeves, J.L., Shaw, C.G. III, and Mayfield, J.E. 1984. The effects of *Trichoderma* spp. isolated from burned and non-burned forest soils on the growth and development of *Armillaria ostoyae* in culture. Northwest Science 64:39-44.

Schultz-Blitz, B. 1991. Vegetation management plan Bird Creek Campground. USDA Forest Service, Alaska Region, Biological Evaluation R10-MB-162. 10pp.

Thies, W.G. 1990. Effects of prescribed fire on diseases of conifers. Chapter 11, Pp. 117-121. In: J.D. Walstad, S.R. Radosevich, and D.V. Sandberg (eds.). Natural and prescribed fire in Pacific Northwest forest. Corvallis, Oregon: Oregon State University Press.

Tkacz, B. and Schmitz, C. 1986. Association of an endemic mountain pine beetle population with lodgepole pine infected by Armillaria root disease in Utah. USDA Forest Service Intermountain Research Station Research Note INT-353, 7pp.

Viereck, L.A. and Schandelmeier, L.A. Effects of fire in Alaska and adjacent Canada – a literature review. BLM- Alaska Technical Report 6, BLM, U.S. Department of Interior, Anchorage, AK.

Whitney, R.D. 1964. Inoculation of eight Saskatchewan trees with *Polyporus tomentosus*. Canadian Department of Forestry, Bi-monthly Progress Report 20(5):3.

Whitney, R.D. 1976. Root rot of spruce and balsam fir in northwestern Ontario I. Damage and implications for forest management. Dep. Environ. Canadian Forest Service, Sault Ste. Marie, Ontario Report O-X-241.

Whitney, R.D. 1977. *Polyporus tomentosus* root rot of conifers. Canadian Forest Service Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario. For. Tech. Rept. No. 18.

Whitney, R.D. 1980. *Polyporus tomentosus* root and butt rot of trees in Canada. Proc. 5th Int. Conference on problems of root and butt rot in conifers. IUFRO, Kassel Germany, L. Dimitri, ed.

Whitney, R.D. 1995. Root-rotting fungi in white spruce, black spruce, and balsam fir in northern Ontario. Canadian Journal of Forest Research 25:1209-1230.

Whitney, R.D. and Bohaychuk, W.P. 1976. Pathogenicity of *Polyporus tomentosus* and *P. circinatus* on seedlings of 11 conifer species. Canadian Journal of Forest Research 6:129-131.